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Microphotonic Steered Beam Technology

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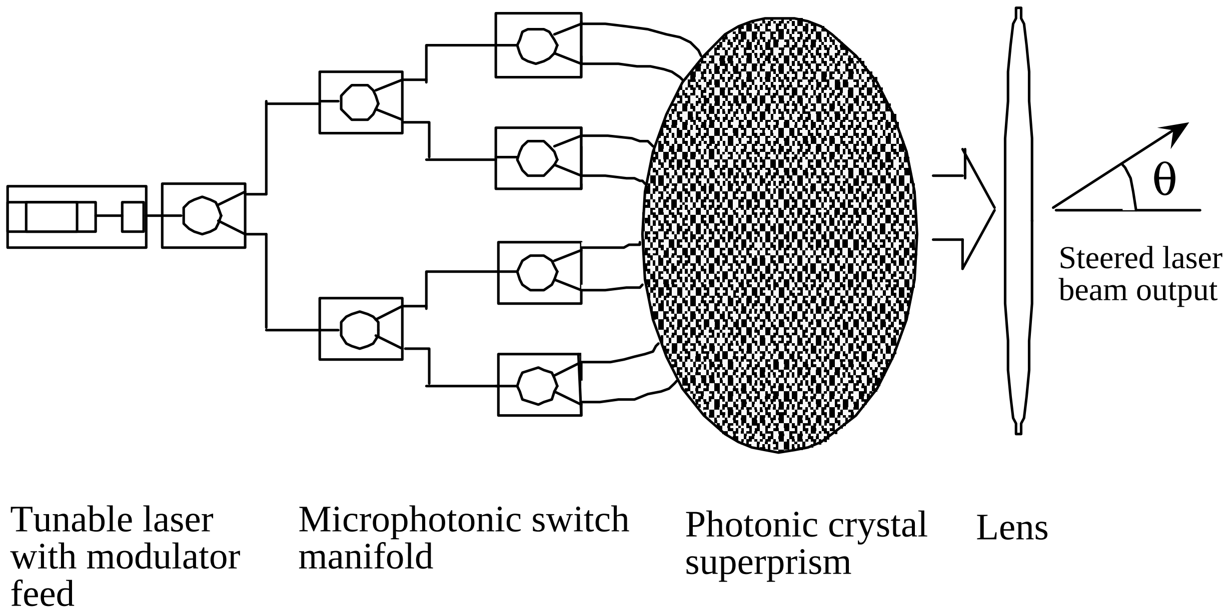
Outline

- Overview
- One-dimensional dispersive elements
- Two-dimensional dispersive elements
- Capabilities
- Near-term goals

Technical Overview



Technical Overview

- The main effort will be the design and creation of novel devices which address the needs of a laser-based beamsteering transmitter for Gb/s communication.

- The approach uses a wavelength tunable DFB and a highly dispersive optical element for beam steering

- Candidate dispersive elements to be developed include the photonic crystal superprism.

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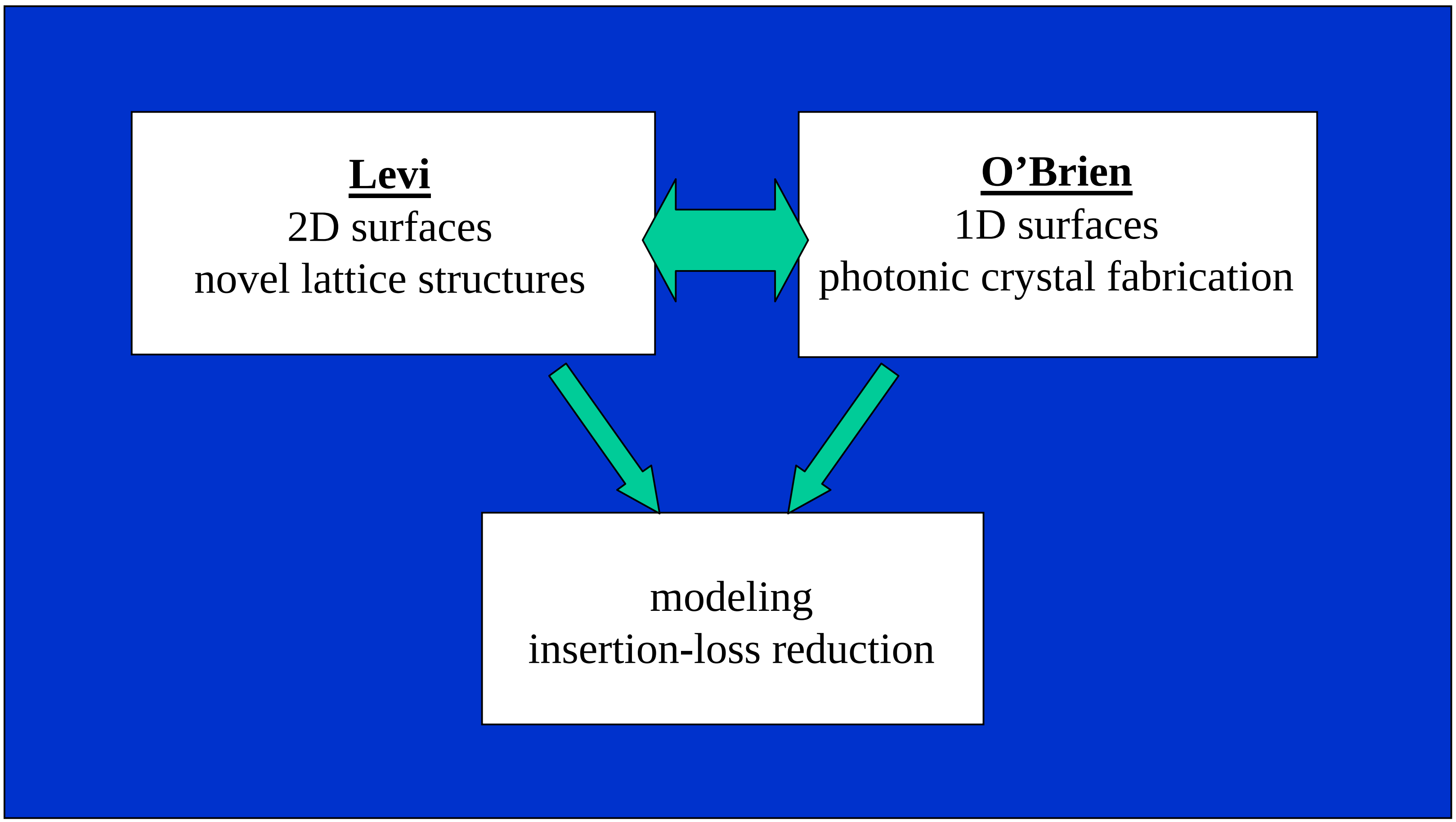
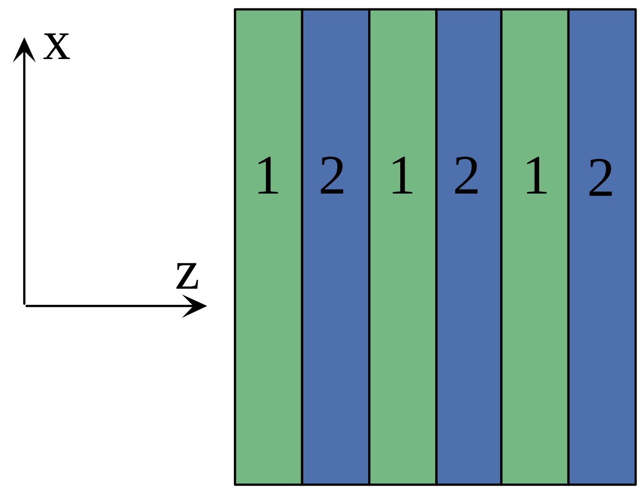
Organization



Model for Two-Dimensional Propagation in a One-Dimensional Lattice



The spatial dependence of the electric field is given by

$$E(x,z) = \left[a_n^{(\alpha)} e^{-ik_{\alpha z}(z-n\Lambda)} + b_n^{(\alpha)} e^{ik_{\alpha z}(z-n\Lambda)} \right] e^{-ik_x x}$$

$\alpha = 1,2$

n labels unit cell

$$k_{\alpha z} = \sqrt{\left(\frac{n_\alpha \omega}{c}\right)^2 - k_x^2}$$

The field is a Bloch wave, so the field in one unit cell is simply related to the field in the next unit cell.

$$\begin{pmatrix} a_{n-1}^{(\alpha=1)} \\ b_{n-1}^{(\alpha=1)} \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} a_{n}^{(\alpha=1)} \\ b_{n}^{(\alpha=1)} \end{pmatrix}$$

or

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} a_{n}^{(\alpha=1)} \\ b_{n}^{(\alpha=1)} \end{pmatrix} = e^{ik_{Bloch} z} \begin{pmatrix} a_{n}^{(\alpha=1)} \\ b_{n}^{(\alpha=1)} \end{pmatrix}$$

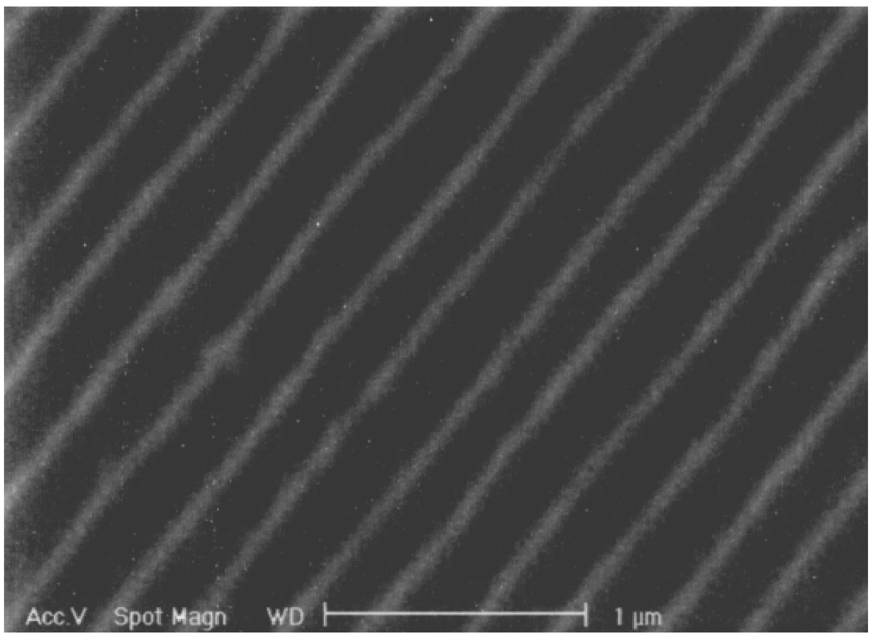
Solving the eigenvalue relation gives the dispersion relation

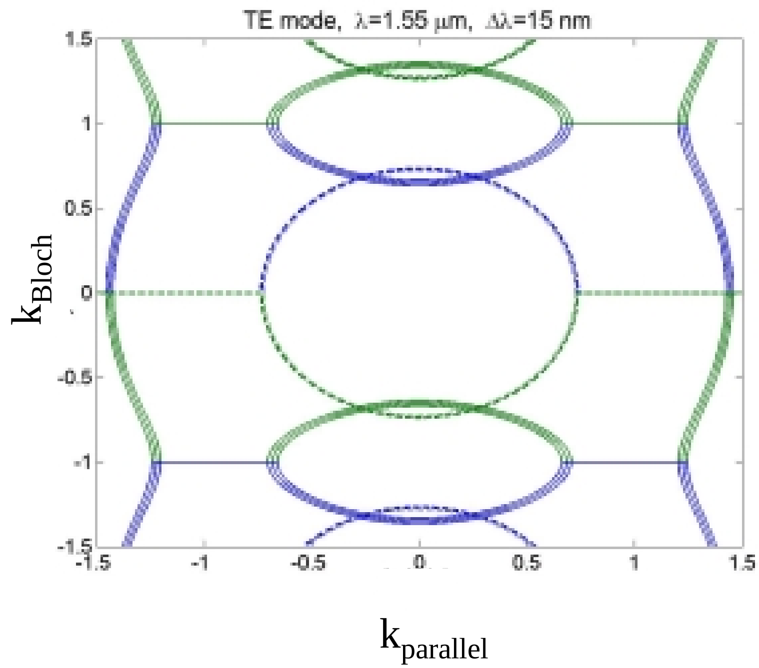
$$\boxed{k_{Bloch} = \frac{1}{\Lambda} \cos^{-1}\left[\frac{A+D}{2}\right]}$$

$$A = e^{ik_{1z}a}\left[\cos(k_{2z}b) + \frac{i}{2}\left(\frac{k_{2z}}{k_{1z}} + \frac{k_{1z}}{k_{2z}}\right)\sin(k_{2z}b)\right]$$

$$D = e^{-ik_{1z}a}\left[\cos(k_{2z}b) - \frac{i}{2}\left(\frac{k_{2z}}{k_{1z}} + \frac{k_{1z}}{k_{2z}}\right)\sin(k_{2z}b)\right]$$

One-Dimensional Grating and Dispersion Relation





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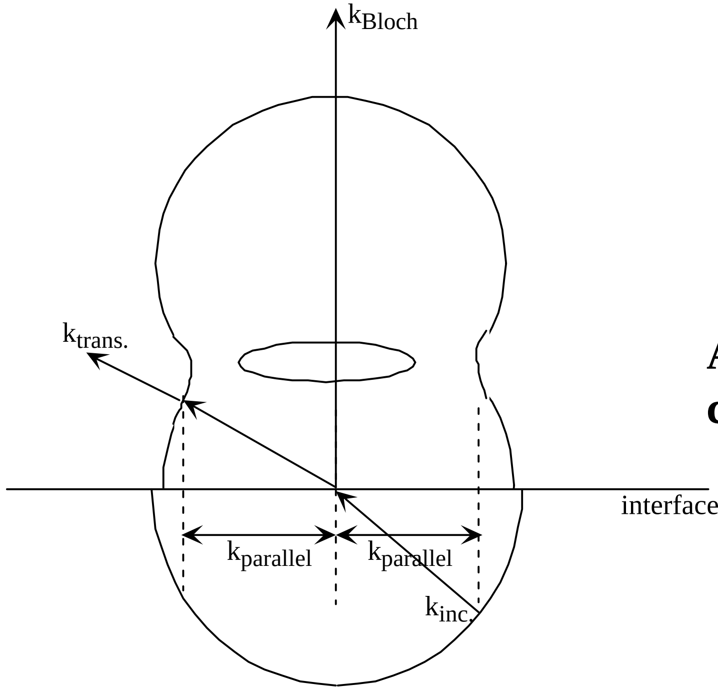
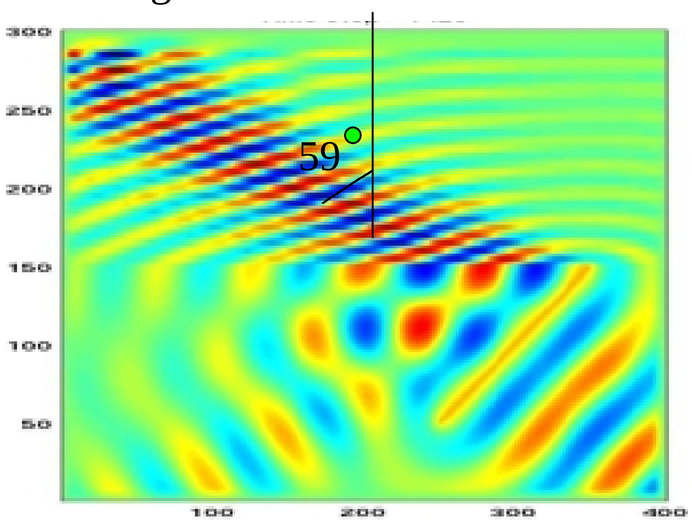
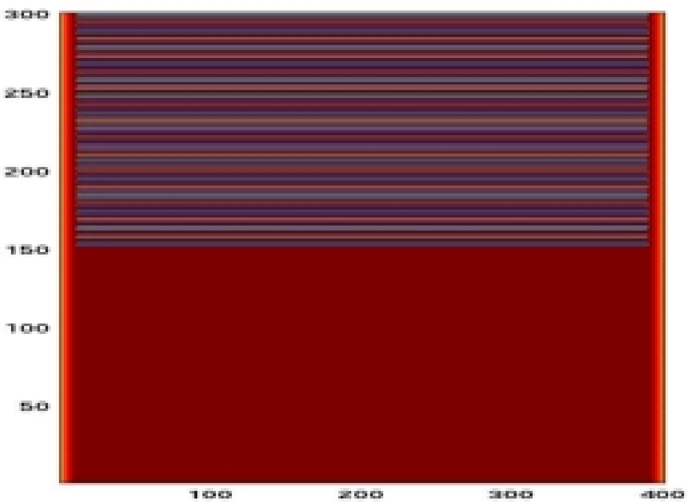


At a fixed angle, as the incident wavelength changes, the transmitted beam direction changes

Magnitude of the electric field

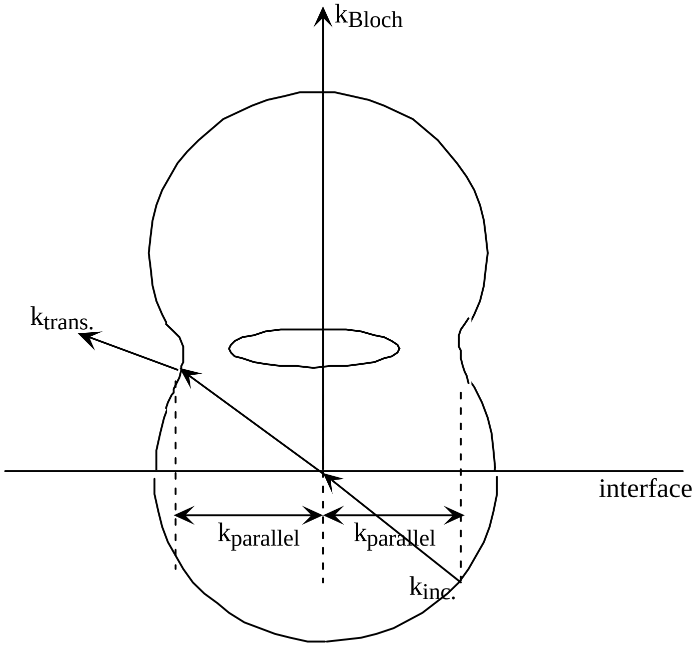


Dielectric structure

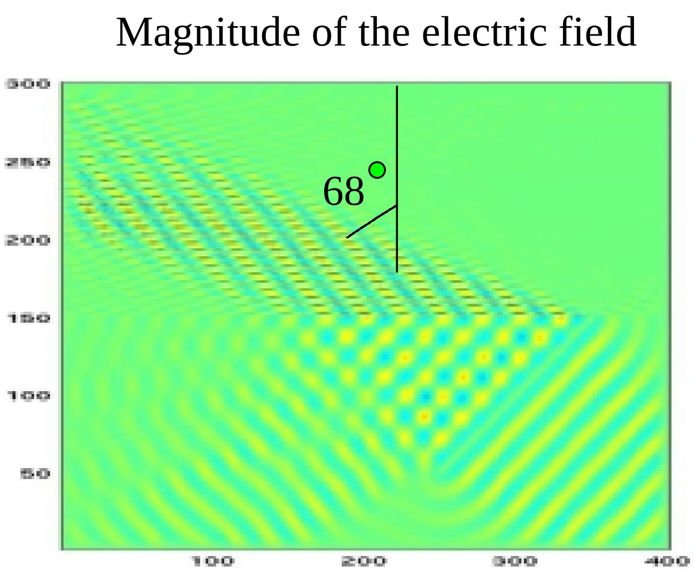


1D DBR

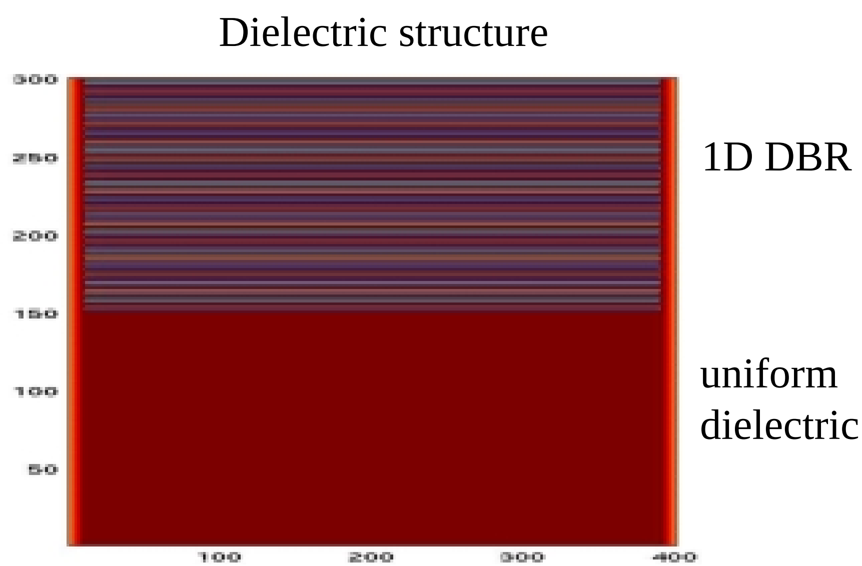
uniform dielectric



k_{Bloch}
$k_{trans.}$
interface
$k_{parallel}$
$k_{parallel}$
$k_{inc.}$



Magnitude of the electric field
68°
300
250
200
150
100
50
100
200
300
400

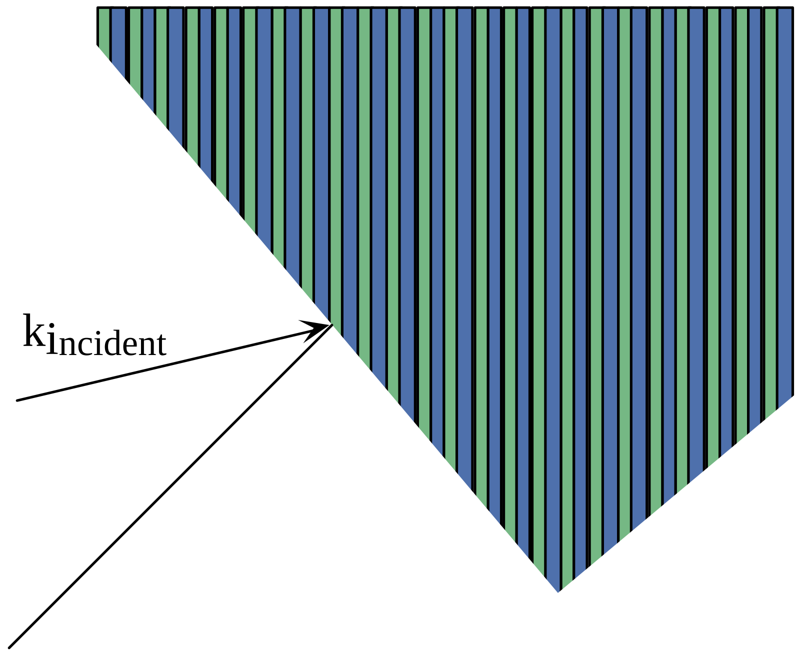


Dielectric structure
1D DBR
uniform dielectric
300
250
200
150
100
50
100
200
300
400

Steering Estimate

Angle of grating ~ 40°

For $\Delta\lambda$ = 15 nm
$\Delta\Theta$(output) = 14°



Early work on beamsteering in 1D

R. Zengerle, “Light propagation in singly and doubly periodic planar waveguides,” J. Mod. Opt., **34**, (1987)

P. St. J. Russell, “Optics of Floquet-Bloch Waves in Dielectric Gratings,” Appl. Phys. B., **39** (1986)

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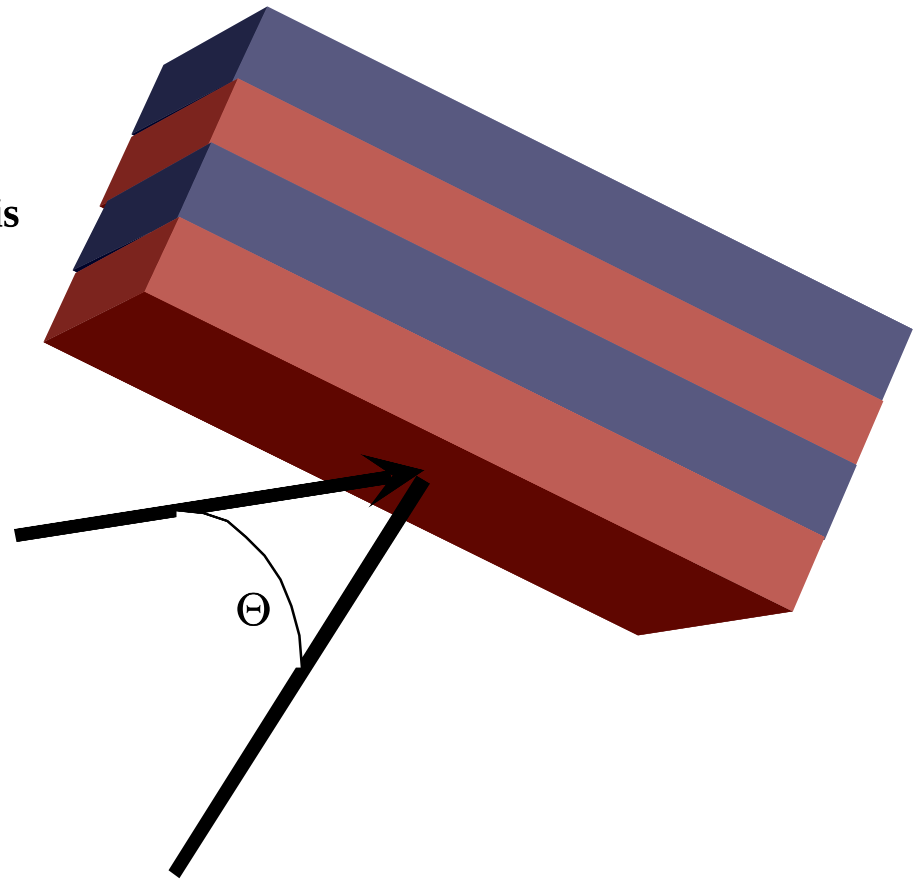
2D steering with 1D grating

For a layered structure, the dispersion surface is rotationally symmetric about the axis of periodicity



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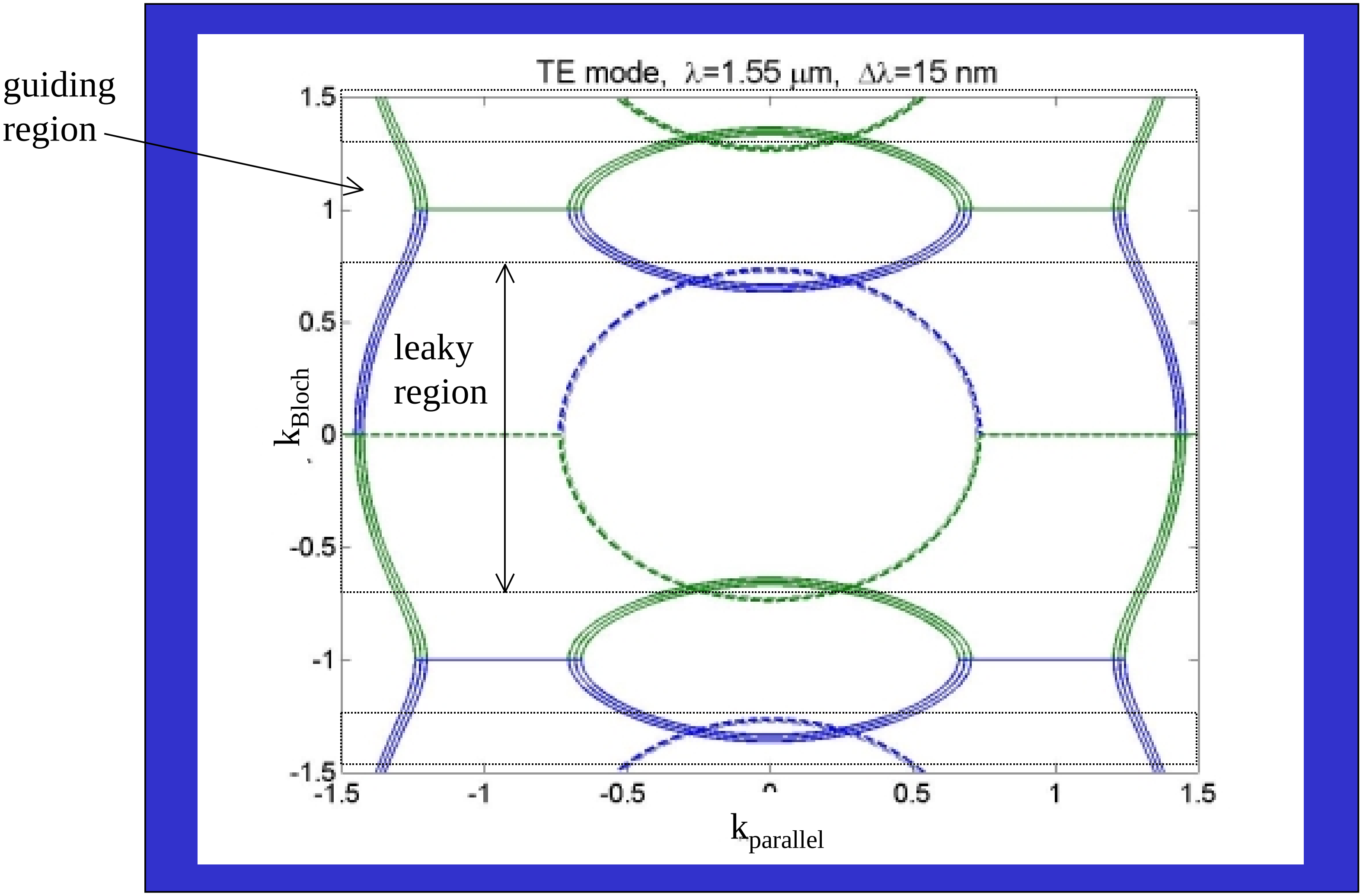
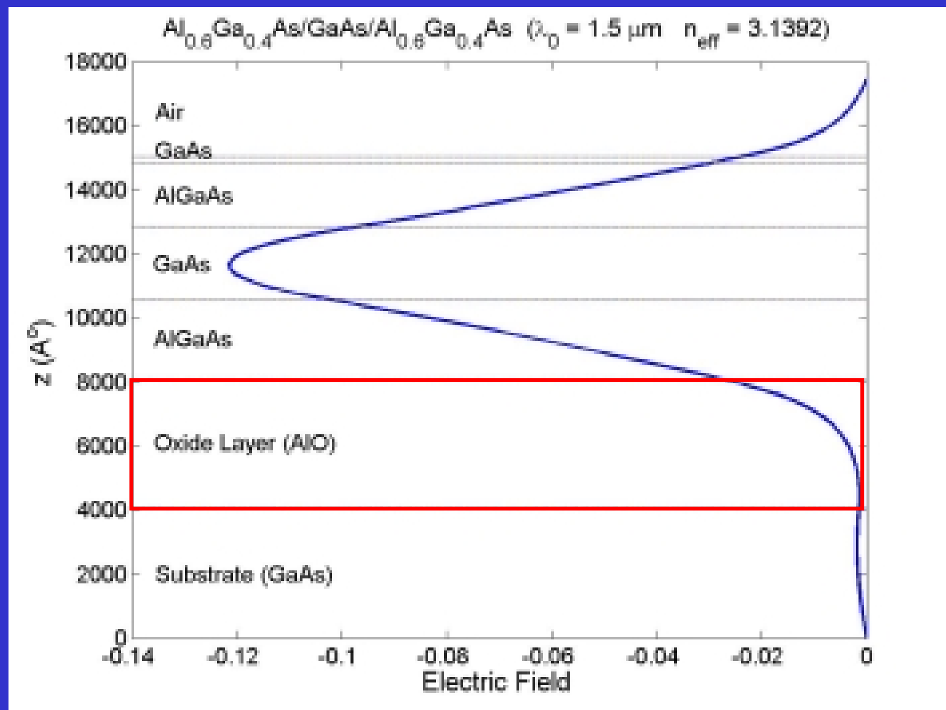
Guiding in the Vertical Direction



Only the regions outside the substrate dispersion circle will not couple radiation into the substrate

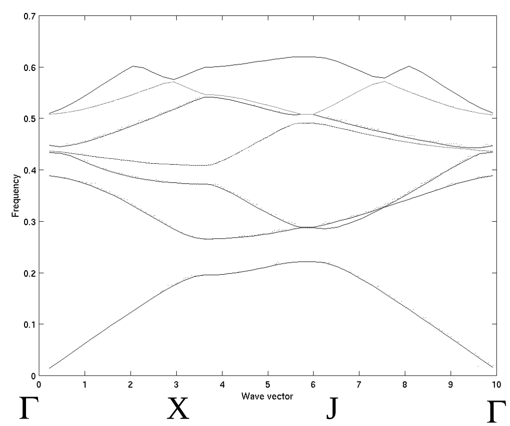
Waveguide Epitaxy



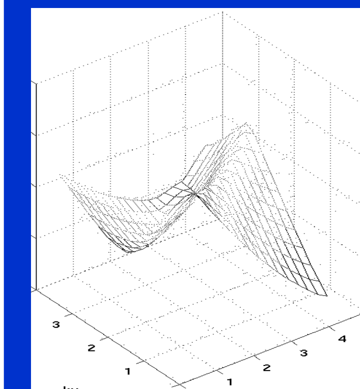
The AlO layer isolates the waveguide from the high-index substrate

Photonic Crystalline Optics

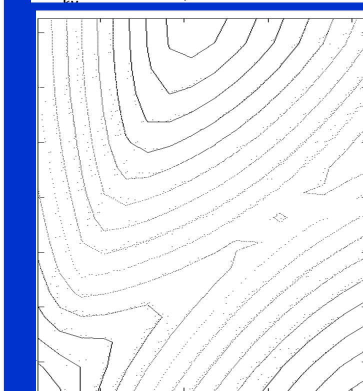
TE Bands for 2D Hexagonal Lattice



$$\vec{v}_g = \nabla_{\vec{k}} \omega(k)$$



frequency surface



constant frequency contours

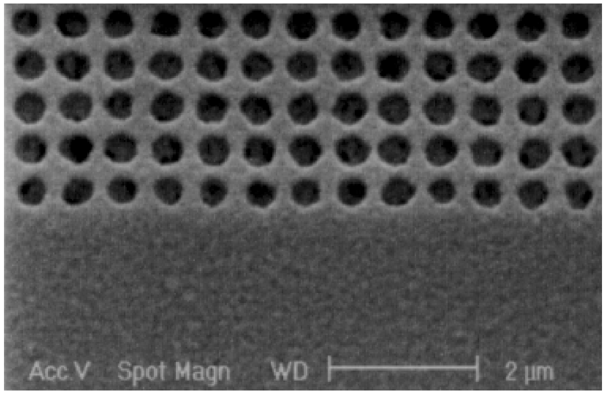
Dispersive propagation allows separation and manipulation of many wavelengths independently.

H. Kosaka, et al., “Superprism phenomena in photonic crystals,” Phys Rev B., **58** (1998)

Advantages of Two-Dimensional Structures

- Highly dispersive region no longer appears only at the zone boundary

- There are more Bragg planes which means more flexibility in the shape of the dispersion surface



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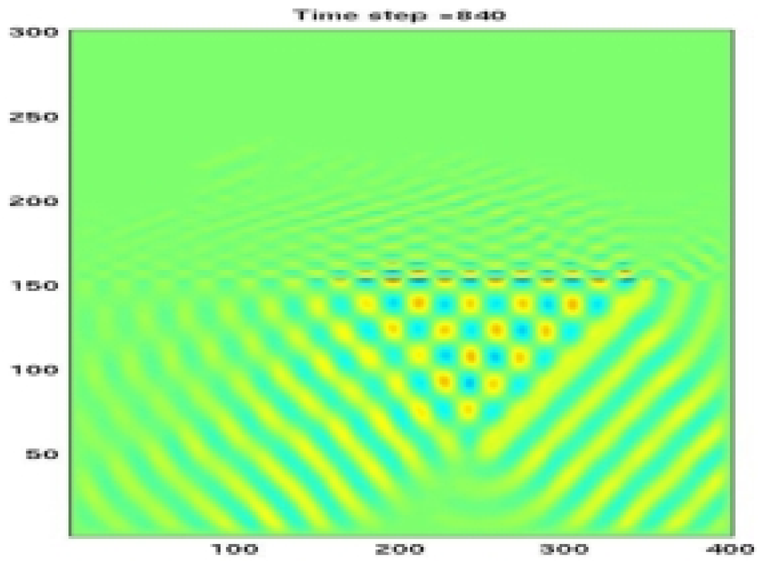
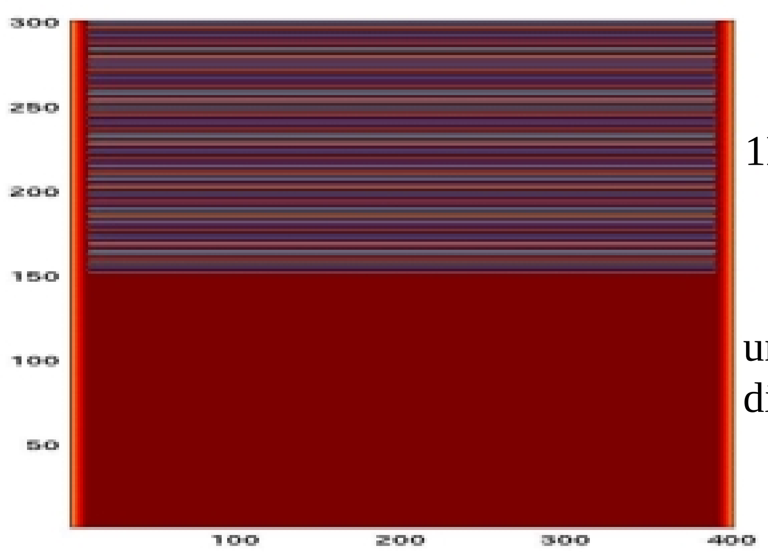
Producing a Low-Insertion Loss Device is an Important Goal





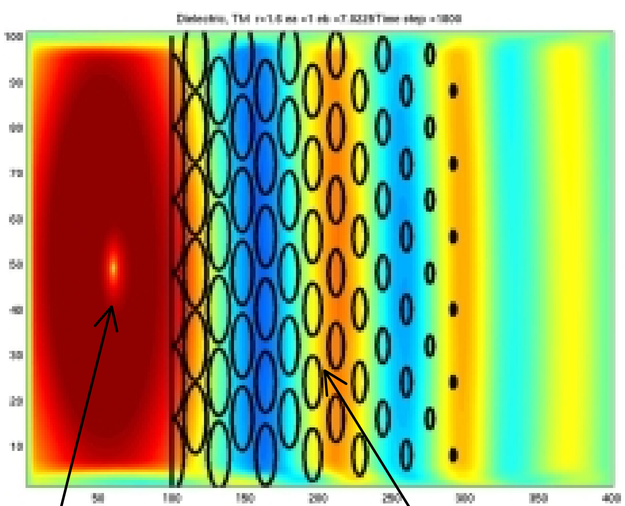
1D DBR

uniform dielectric

FDTD calculation showing reflection at the Bragg condition

Efficient coupling into the modulator is important

We will investigate means of reducing the insertion loss into the dispersive optical element.



point source in free space

dielectric with adiabatic lattice change

- **AR coatings**
- **adiabatic lattice changes**

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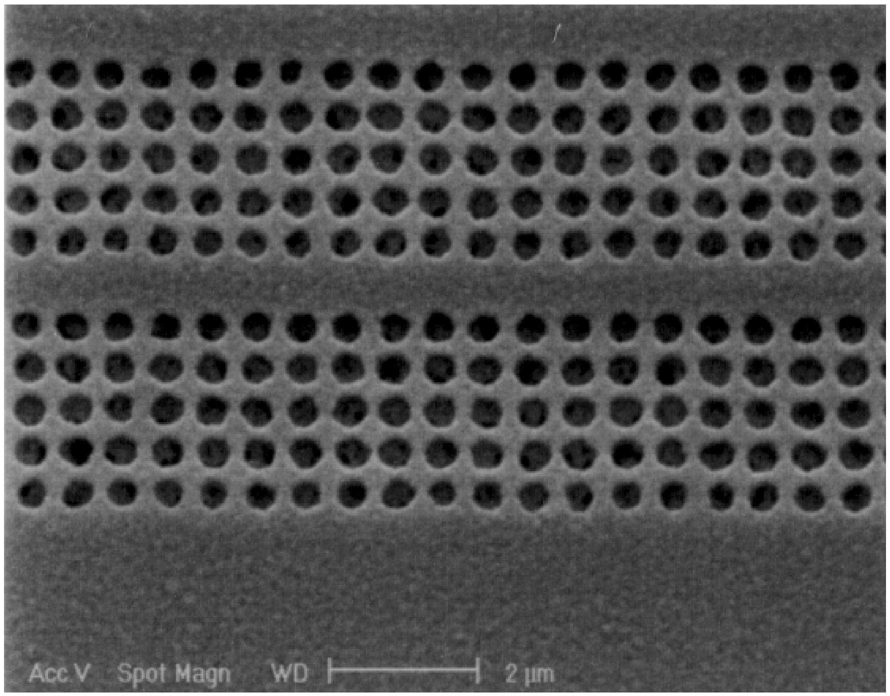
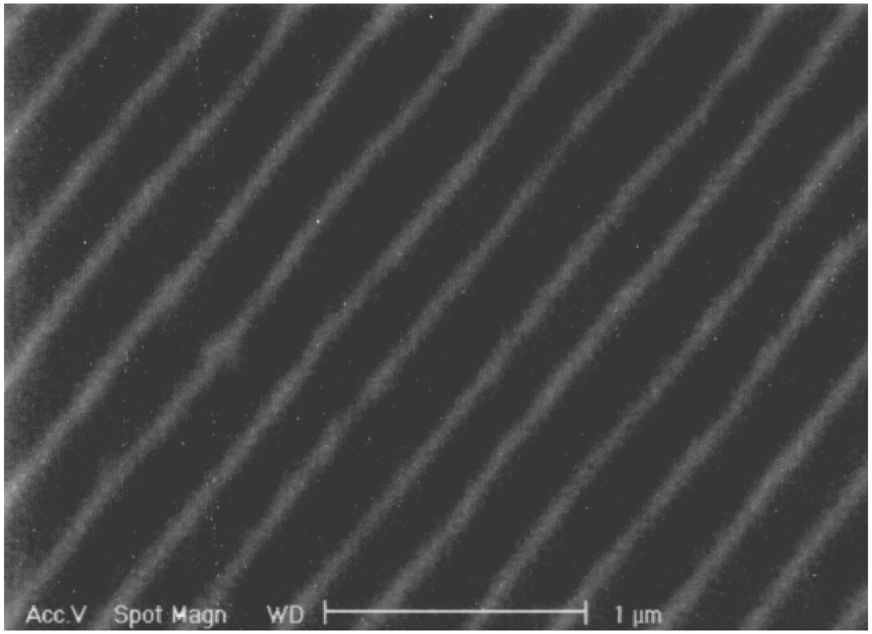
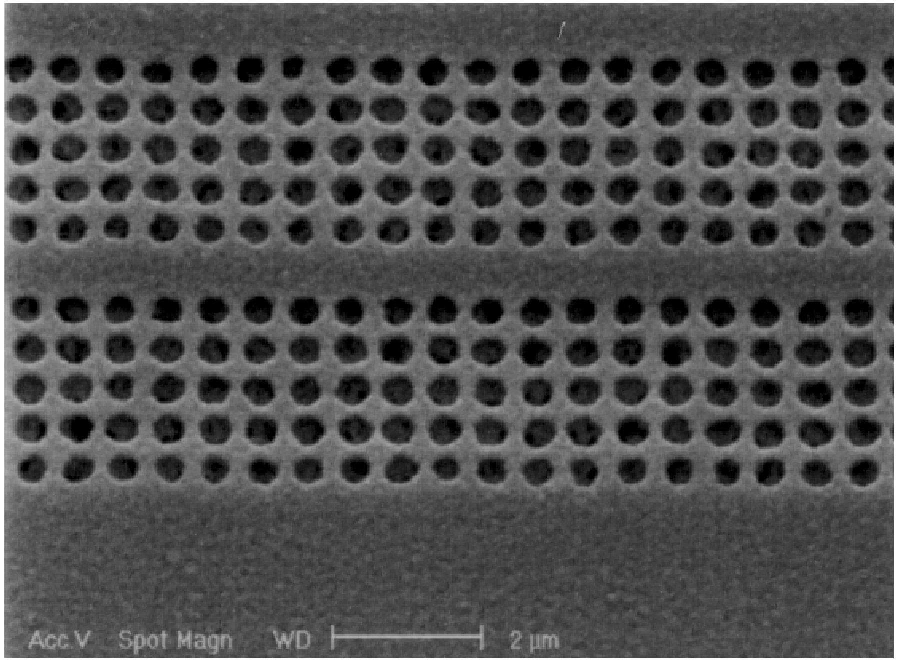
Photonic Crystal Fabrication

- Defined by e-beam lithography
- Pattern transfer by ion beam mill, reactive ion etch, and electron cyclotron resonance etch





1D and 2D PBG Micrographs



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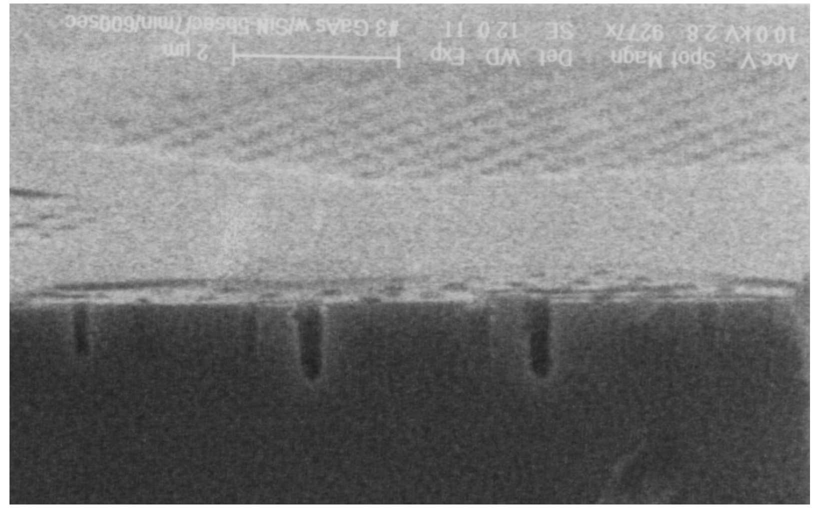
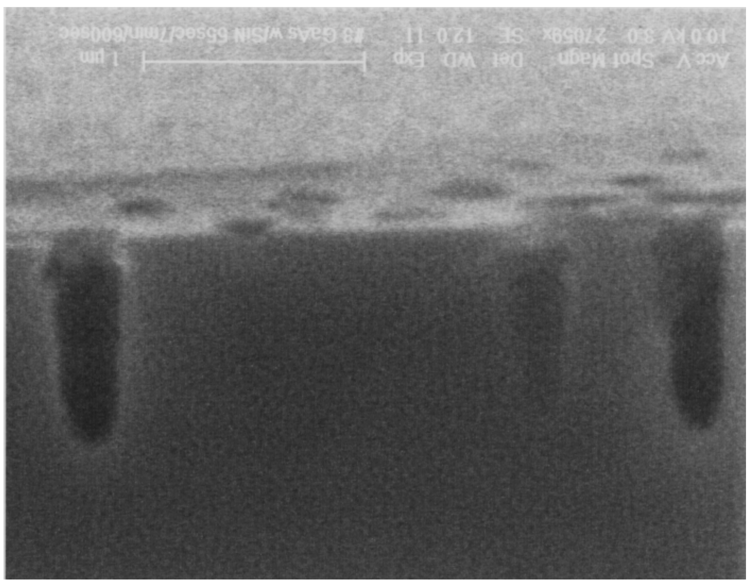
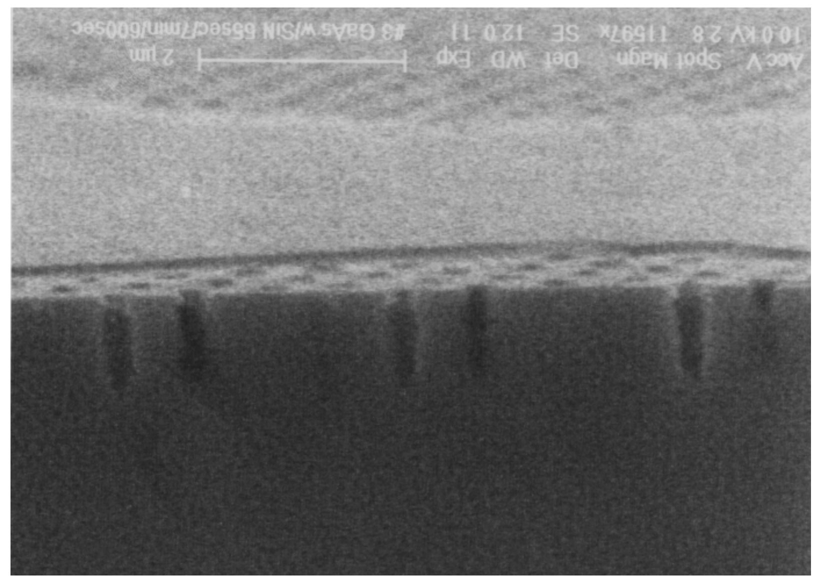
GaAs PBG Cross-Sections after ECR etch

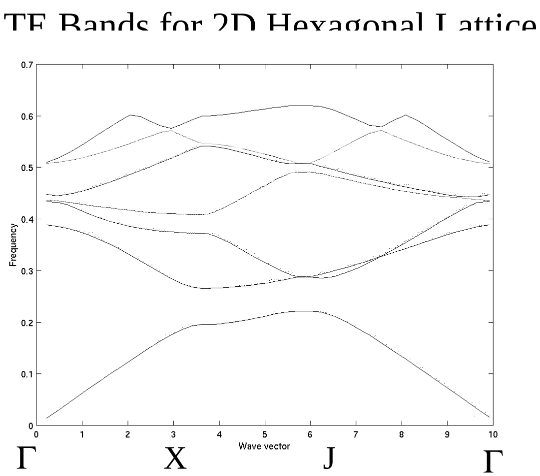




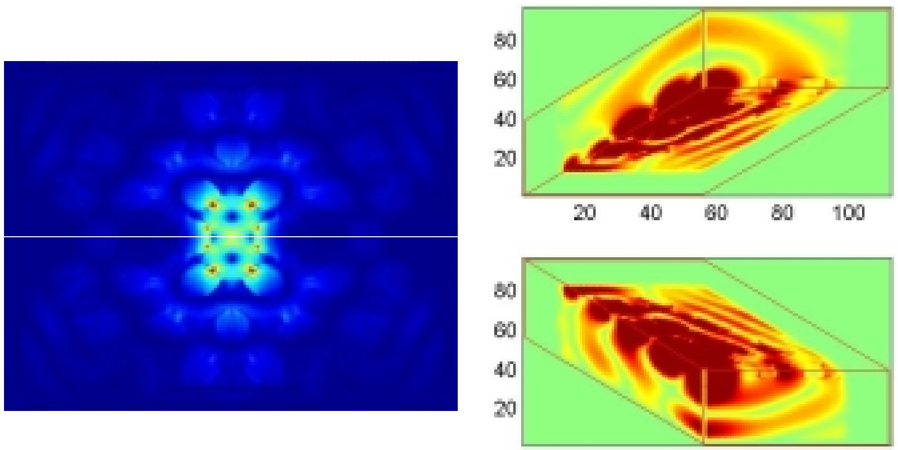


Numerical Tools

- Finite-difference time-domain



Bandstructure and dispersion relations



Two and three-dimensional fields calculations

Near-Term Goals

- **Design, fabricate, and characterize one-dimensional gratings**
- **Design, fabricate, and characterize two-dimensional gratings**
- **Model insertion loss, and evaluate candidate solutions**